Micro-Computed Tomography Analysis of Fit of Ceramic Inlays Produced with Different CAD Software Programs

Keywords

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ABSTRACT

Purpose: The aim of this study was to evaluate marginal and internal fit of ceramic inlays designed with different computer-aided design software programs. Materials and Methods: 11 typodont mandibular first molars were prepared as a ceramic class II mesio-occlusal inlay cavity. Teeth were scanned using 3Shape TRIOS Intraoral Dental Scanner. The scan data, which was obtained in the form of a STL file, was designed in three different CAD systems (CEREC, KaVo, and Planmeca). The obtained STL scan data was exported to design inlay using three different CAD systems (CEREC, KaVo, and Planmeca). An independent 5-axis milling unit was used to manufacture the feldspatic inlay restorations. 11 measurements for each teeth were made by using micro-ct to evaluate the marginal and internal fit. One-way ANOVA was used to determine the statistical difference between groups, and Tukey posthoc test was used to determine intra-group differences. Results: According to repeated ANOVA test results, a statistically significant difference was found between the groups for the variables A, D, and F. There was no statistically significant difference between the groups in linear measurements for other measurement points and volumetric measurements (p>0.05). Conclusion: Software programs of different systems affects the marginal and internal fit of inlay restorations.

INTRODUCTION

There has been a significant increase in the use of tooth-colored ceramic restorations in recent years. The development and strengthening of adhesive cements also caused minimally invasive dentistry to attract more attention. Preservation of the tooth structure is of critical importance for the longevity of the teeth and restoration.[1] An inlay restoration is a type of intracoronary restorations that do not involve the cusps of the teeth and is more conservative than crown restorations.[2] In full-crown restorations, 67.5% to 75.6% of dental tissue is removed whereas this rate is about 20% for inlay restorations.[3]

The success of ceramic restorations is influenced by many factors. The most important ones are the marginal seal and thickness of the adhesive cement.[4,5] Marginal and internal fit of inlay and crown restorations are very important for clinical success.[6] Secondary caries, microleakage, and periodontal inflammation are associated with a poor marginal fit. Therefore, a good marginal fit is essential for success.[5,7,8] On the other hand, the gap between restoration and dental tissue is filled with adhesive cement;

which is also closely related to the success of the restoration. Restoration must be mechanically supported by the tooth structure for an effective function.[7] Restorations with poor adaptation are supported by cement, which is weaker than the tooth structure, and it affects the durability of this restoration. Therefore, the internal fit of ceramic inlay restorations should be homogeneous. There is limited information about the internal fit of ceramic inlay restorations.[6]

For the ceramic restorations, the cement gap value has been reported as about 25-40 µm, however, this marginal gap is quite difficult to achieve. The clinically acceptable marginal cement gap has been reported to be between 120-150 µm.[9,10] The marginal cement gap has been reported to be 58-200 micrometers for the restorations manufactured via Computer-Aided Design/Computed-Aided Manufacturing (CAD/CAM) systems.[9,11] It has been further reported that the gap should be less than 90 micrometers for CAD/CAM restorations.[12]

The production steps of the restorations manufactured via CAD/CAM technology include data acquisition, data processing, and production. Each of these stages has equal importance for good restoration adaptation and an error that may occur during any of these stages may lead to distortion in restorations. Therefore, the scanning stage, a special software program, and milling device are the determining factors in the restorations produced with CAD/CAM systems.[9,13]

Different methods including sectioning, replica and direct measurement have been used to evaluate the marginal and internal fit of the restorations. However, there might be some errors in the evaluation of marginal and internal fit via these methods. In recent years, micro-computed tomography (CT) has been increasingly used in prosthetic dentistry and particularly in evaluating the adaptation of restorations. The micro-CT method is relatively more expensive than other methods, but it is a non-destructive method. This 3D high-resolution imaging system provides detailed information during the evaluation of the adaptation between the restoration and tooth, without damaging the sample.[4,8,14,15]

There are numerious studies examining the effects of different scanners, different milling devices and different versions of design programs on the marginal and internal fit of restorations. However, there are no studies to date examining the effect of different design programs on the adaptation of restorations. Many clinicians use only intraoral scanners in their clinics, and send intraoral scaning data to laboratories for the design and production of restorations. The fit of the restorations is thought to be affected not only by other parameters but also by CAD software. This study aimed to evaluate the marginal and internal fit of CAD/CAM inlay restorations designed using different software programs. The null hypothesis of the study is that the marginal and internal fit of the inlay restorations would not be affected by the use of different CAD/CAM programs.

MATERIALS AND METHODS

A total of 11 typodont enamel–dentin–pulp-based mandibular first molars (Frasaco, Germany) were prepared as a ceramic class II mesio-occlusal inlay cavity by a single physician using an intensive bur set (801400; Intensive FG Ser-Inley III Extended, Intensive Swiss Dental Products, Montagnola, Switzerland) and controlling the occlusion. Preparation was made with a cavity depth of 2-2.5 mm, cavity width of at least 3 mm in the occlusal region, convergence angle of 6-10 degrees, the mesial cavity base being about 1.5 mm away from the gum, and rounded inner edges and sharp outer edges.

The relationship of 11 prepared teeth with neighbor teeth and occlusion were scanned using 3Shape TRIOS Intraoral Dental Scanner and optical measurement was obtained. The scan data was received from the system in the form of an STL file. The scan data, which was obtained in the form of an STL file, was designed in three different CAD systems (CEREC, KaVo, and Planmeca). All designs were made by a single physician. The design proposed by the program was not intervened except for minor corrections in the margin drawing to eliminate the physician-related errors. In all three systems, the cement gap was set to 80 micrometers for occlusal and axial walls and 25 micrometers for the marginal edge. No other parameters were intervened. A total of 33 inlay restorations were designed in accordance with the order within each system and the programs of each system. A total of 33 inlay designs taken from each system for 11 teeth were obtained as STL files and they were manufactured using feldspathic ceramic blocks (48872; VITA Zahnfabric, Bad Sackingen, Germany) on an independent five-axis device (DMC5020, DentMaster).

The restoration was placed in the cavity and fixed using radiolucent paraffin tapes to prevent its movement during micro-ct scanning. When necessary, minimal corrections were made and restorations were ensured to be completely fitted in the inlay cavity.

Skyscan 1275 (Skycan, Kontich, Belgium) device with high-resolution scanning capacity was used for micro-CT scans. Scanning parameters were set as follows: 125 kVp, 80 mA, 24 µm/pixel and a rotation step of 0.2. A 1-mm thick aluminum filter was used to prevent radiological artifacts that might occur during the scans. Then, each scanned sample was reconstructed individually using NRecon (version 1.6.4.8 Skycan, Kontich, Belgium) software. Other radiological artifacts that might appear during the scan were eliminated with this software. The two-dimensional (2D) axial projection was obtained from the reconstruction samples. These 2D axial projections were, then, transferred to CTan (version 1,14,4,1 Skycan, Kontich, Belgium) software to perform mathematical analysis.

Substance volumes were determined with the gray-color values to be included in the Region of Interest (ROI) by applying adaptive interpolation of the substructure where each sample contacted with inlays. The amount of substance in the ROIs showed the solid volume of the sample and the amount of opening in the ROIs showed the gap. Then, the gap values of the ROIs were subject to statistical comparison. Colored and 3D images were obtained from the samples using CTvox and CTvol software *(Figure 1)*.

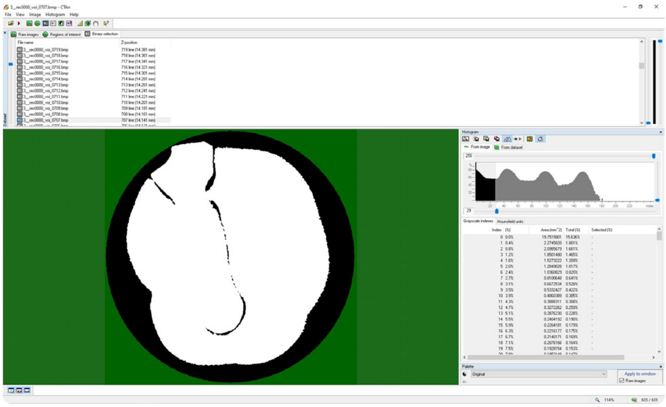

Figure 1: Colored and 3D images were obtained from the restorations using CTvox and CTvol software

DataViewer software (version 1,5,6.2 Skycan, Kontich, Belgium) was used for the preparation for 2D measurements. Axially reconstructed images could be examined in 2D coronal and sagittal images with this software. Images of the midcoronal and modified sagittal sections of the inlays were obtained with this software *(Figure 2a, Figure 2b)*. The modified sagittal image for inlays was taken from the area where the restoration and the tooth tissue were in full contact with at least four edges in the mesial. These images were again uploaded into the CTan program and 2D linear measurements were performed. Measurements were made at six different points for midcoronal sections and five points for modified sagittal sections *(Figure 3a, Figure 3b)*. A total of 363 measurements, 11 measurements for each sample, were made. The A, F, T and Z points were evaluated to determine marginal fit and B, C, D, E, V, X, Y points were evaluated to determine internal fit.

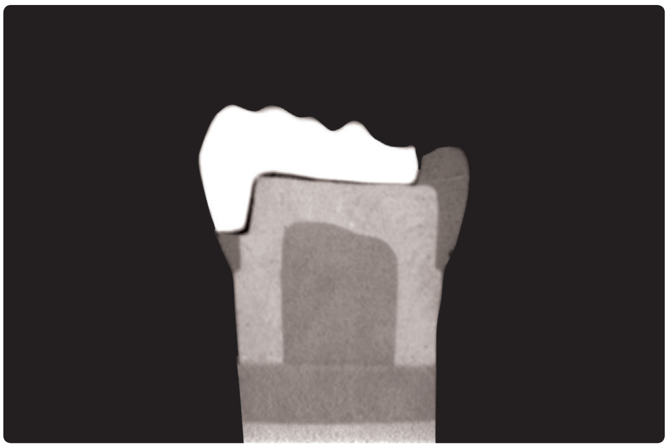

Figure 2a: Mid-coronal section image

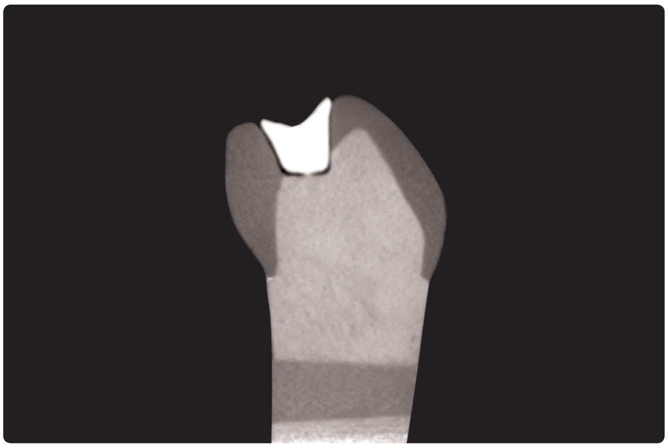

Figure 2b: Modified sagittal section images

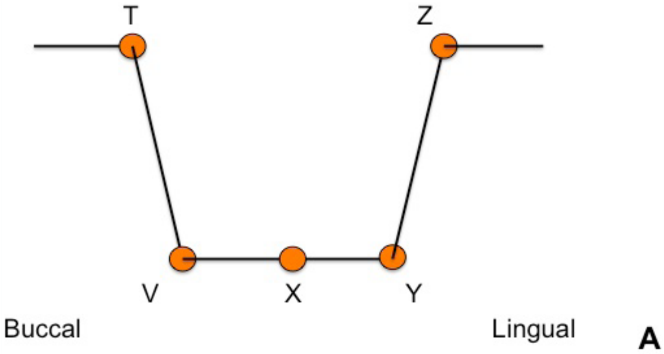

Figure 3a: Schematic representation of 5 measurement locations in coronal section

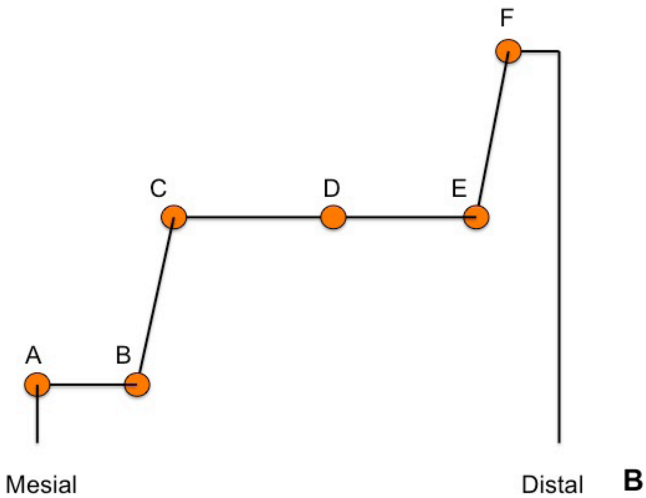

Figure 3b: Schematic representation of 6 measurement locations in sagittal section

All statistical analyses were performed using SPSS Statistics for Windows version 21.0 (SPSS Inc., Chicago, IL, USA). Shapiro-Wilk test was used to evaluate the parametric or nonparametric distribution of the groups. One-way ANOVA was used to determine the statistical difference between groups, and Tukey posthoc test was used to determine intra-group differences. P value of <0.05 was considered statistically significant in all tests.

RESULTS

Table 1 shows the mean and standard deviation values for each measurement point in three different study groups.

According to repeated ANOVA test results, a statistically significant difference was found between the groups for the variables A, D, and F in the midcoronal cross-section in 2D linear measurements ($p < 0.05$). In the Tukey posthoc analysis, the values of the KaVo design for the variables A and D were found to be statistically higher than those of the CEREC design. In linear measurements, the values of CEREC design for F value were statistically higher than those of Planmeca and KaVo designs. However, there is no statistically significant difference between the Planmeca and KaVo groups. There was no statistically significant difference between the groups in linear measurements for other measurement points and volumetric measurements ($p > 0.05$) *(Table 1)*.

DISCUSSION

Based on the results of this study, the null hypothesis of the study was not accepted. Data obtained from this study has shown that marginal and internal fit may statistically differ between ceramic inlay restorations designed in different software programs using the same and independent scanner and milling device.

Different results are obtained due to the scanning, design and manufacturing stages in CAD/CAM restorations.[16] In the literature, there are studies comparing the scanners with each other, scanners and conventional measurement methods, different versions of design programs, and different production unit types and evaluating their effects on marginal and internal fit.[4,12,14,17-19] However, there was no study in which marginal and internal fit has been evaluated only depending on the software. Since the intraoral scanner and milling unit are the

Table 1: Statistical analysis of the results

COR	Groups	Mean± SD (μm)	SAG	Groups	Mean± SD (μm)
a	1	48.8±0.07[a]	**t**	1	104.1±0.11 [a]
	2	192.4±0.13 [b]		2	121.4±0.11 [a]
	3	117.1±0.10 [ab]		3	094.6±0.08 [a]
b	1	248.1±0.07 [a]	**v**	1	127.2±0.10 [a]
	2	232.4±0.10 [a]		2	199.0±0.13 [a]
	3	278.4±0.15 [a]		3	198.9±0.10 [a]
c	1	88.5±0.12 [a]	**x**	1	085.5±0.16 [a]
	2	63.2±0.11 [a]		2	190.4±0.13 [a]
	3	0.72±0.02 [a]		3	115.6±0.09 [a]
d	1	77.0±0.04 [a]	**y**	1	167.1±0.10 [a]
	2	229.6±0.12 [b]		2	160.5±0.10 [a]
	3	150.2±0.16 [ab]		3	246.5±0.20 [a]
e	1	134.3±0.12 [a]	**z**	1	058.7±0.11 [a]
	2	179.2±0.08 [a]		2	76.0±0.10 [a]
	3	224.0±0.17 [a]		3	90.2±0 [a]
f	1	272.2±0.11 [a]	**D3 (mm^3)**	1	4.6956±2.14 [a]
	2	117.0±0.13 [b]		2	5.6947±1.57 [a]
	3	138.1±0.11 [b]		3	5.2459±1.56 [a]

COR: coronal; SAG: sagittal 1: CEREC; 2: KaVo; 3: Planmeca D3: Volumetric analysis
Each group was evaluated within itself while statistical differences were written in the table

same for the teeth prepared for three different software programs, the difference is completely due to software.

In a study by Haddai *et al.*[19] evaluating the effect of different versions of the same design program on the adaptation of the restoration with the tooth, different versions of the software program have been shown to affect the adaptation of the restoration. Similarly, different results were obtained from different software programs in the present study.

Linear measurements were made from 11 points in two different sections to evaluate marginal and internal fit. The A, F, T, and Z points were used to evaluate marginal fit whereas other points were used to evaluate internal fit. According to the results of the present study, the Planmeca group was seen to have the best results in terms of marginal fit in the measurements performed in the midcoronal section. In the measurement points in which internal fit was evaluated, the amount of internal misfit was high in the KaVo group for only one point whereas there was no difference between the CEREC and Planmeca groups.

In our study, besides the linear measurements, we also performed volumetric measurements for each group. The amount of gap between the preparation and the tooth surface was measured to cover the entire area. No statistically significant difference was observed between the three groups in this regard. The literature review has shown that there is no study in which volumetric measurements are performed to evaluate the adaptation of the restoration. Linear measurements have been used for the evaluation.[4,14,16] Volumetric measurements were performed to support linear measurements. However, it is thought that volumetric measurements are inadequate to provide information about restoration adaptation alone and the linear measurements are necessary particularly for evaluating marginal fit. Although the total gap between restoration and tooth surface is similar in volumetric measurements, the linear measurements have shown a difference particularly in marginal fit and therefore, volumetric measurements have been inadequate in this regard.

The acceptable marginal gap for CAD/CAM restorations is reported to be 58-200 micrometers.[9,11] Studies have shown that good marginal fit results in less microleakage, periodontal disease, and secondary caries.[7,8,16,20] In linear measurements made from measurement points used to evaluate marginal fit in the present study, the mean marginal gap value was found to be above 200 micrometers for the measurement point F in the CEREC group. For all other measurement points and study groups, the marginal gap value remained below 200 micrometers and was within the clinically acceptable limit.

In a study by Shim *et al.* (2015),[13] the authors have reported that parameter settings affect the adaptation of CAD/CAM restorations. In our study, all parameters were kept constant in the three groups. Thus, the marginal and internal fit n was prevented from being affected by the parameters.

In a study by Son *et al.*,[21] the learning curves of two different CAD software systems were examined and it was shown that the learning curves could be different. All designs were made by a single physician who had previously trained and used all of the three software programs. In the marginal drawing, no intervention was made to parameters, except for minor corrections, against the possibility of developing different ability to learn and use in different design programs and thus, differences arising from learning were minimized.

Compatible with the previous studies in the literature,[4,14,16] micro-CT was used to evaluate the marginal and internal fit of inlay restorations in the present study. Micro-CT is one of the best and recommended methods for evaluating marginal and internal fit. It ensures that high-resolution images are obtained and the samples are not damaged.[8,16] New and repetitive analyses can also be performed with this method which allows 2D and 3D measurements. The micro-CT method further provides quantitative analysis and examination of the internal fit of the restoration, which cannot be carried out via other methods.[22]

In the present study, restorations were fixed with radiolucent paraffin tapes to ensure that they remained stable in the micro-CT device where the sections were taken because the produced inlay restorations were going to be placed in the same tooth preparation of three different groups and it was thought that cement residues could not be cleaned completely and would cause an error.[16] Paraffin tapes were able to hold the restoration fixed on the dental preparation and there was no problem with their removal from the tooth. Thus, dental preparation was not damaged. Furthermore, micro-CT cannot be applied in the presence of insufficient and inappropriate radiographic contrast. There should be an adequate contrast between dental preparation and restoration to ensure an accurate image analysis.[22] In this study, no intervention was made to the interface in measurements between restoration and dental preparation to be able to visualize the dentin, restoration, and marginal and internal gap. Therefore, restorations could not be cemented.

The positions of the samples in the micro-CT system could not be standardized. For this reason, we were unable to perform correlation measurements for the same areas on the surfaces where the restorations produced using three different designs contacted the tooth. The reason for the statistical difference in linear measurements may be due to the non-standardization of the sectional areas because of the non-standardization of the samples in the system. Measurements of the same points following their standardization may be interesting and meaningful in inlay supported restorations.

CONCLUSION

From this study, the following could be concluded:

1. Software programs of different systems affects the marginal and internal fit of inlay restorations.
2. Volumetric measurements can be also important for the evaluation of the fit of the restorations using micro-CT as an adjunct to conventional methods.

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DISCLOSURE

The authors declare that they have no conflict of interest.

REFERENCES

1. Guess, P.C., Schulthesis, S., Wolkewitz, M. and Strub, J.R.. Influence of preparation design and ceramic thickness on fracture resistance and failure modes of premolar partial coverage restorations. *J. Prosthet. Dent.*, 2013;**110**:264.273.
2. Shibata, S., Gondo, R., Araujo, E., Roesler, C.R.M. and Baratieri, L.N. Influence of surrounding wall thickness on the fatique resistance of molars restored with ceramic inlay. *Braz. Oral. Res.*, 2014;**28**:1.8.
3. Edelhoff, D. and Sorenson, J.A. Tooth structure removal associated with various preparation designs for posterior teeth. *Int. J. Periodontics. Restorative. Dent.*, 2002;**22**:241.249.
4. Uzgur, R., Ercan, E., Uzgur, Z., Çolak, H., Yalçın, M. and Özcan, M. Cement thickness of inlay restorations made of lithium disilicate, polymer-infiltrated ceramic and nano-ceramic CAD/CAM materials evaluated using 3D X-Ray micro-computed tomography. *J. Prosthodont.*, 2018;**27**:456.460.
5. Anadioti, E., Aquilino, S.A., Gratton, D.G., Holloway, J.A., Denry, I., Thomas, G.W. and Qian, F. 3D and 2D marginal fit of pressed and CAD/CAM lithium disilicate crowns made from digital and conventional impressions. *J. Prosthodont.*, 2014;**23**:610.61
6. Tidehag, P., Ottosson, K. and Sjögren, G. Accuracy of ceramic restorations made using an in-office optical scanning technique:an vitro study. *Oper. Dent.*, 2014;**39**:308.316.
7. Addi, S., Hedayati-Khams, A., Poya, A. and Sjögren, G. Interface gap size of manually and CAD/CAM-manufactured ceramic inlays/onlays in vitro. *J. Dent.*, 2002;**30**:53.58.
8. Contrepoıs, M., Soenen, A., Bartala, M. and Lavıole, O. Marginal adaptation of ceramic crowns: a systematic review. *J. Prosthet. Dent.*, 2013;**110**:447.454.
9. Sadid-Zadeh, R., Kastavochristou, A., Squires, T. and Simon M. Accuracy of marginal fit and axial wall contour for lithium disilicate crowns fabricated using three digital workflows. *J. Prosthet. Dent*, 2019; doi: 10.1016/j.prosdent.2018.11.003.
10. Fransson, B., Oilo, G. and Gjeitanger, R. The fit of metal-ceramic crowns, a clinical study. *Dent. Mater.*, 1985;**1**:197.199.
11. May, K.B., Russell, M.M., Razzoog, M.E. and Lang, B.R. Precision of fit: the Procera AllCeram crown. *J. Prosthet. Dent.*, 1998;**80**:394.404.
12. Abdel-Azım, T., Rogers, K., Elathamna, E., Zandınejad, A., Metz, M. and Morton, D. Comparison of the marginal fit of lithium disilicate crowns fabricated with CAD/CAM technology by using conventional impressions and two intraoral digital scanners. *J. Prosthet. Dent.*, 2015;**114**:554.559
13. Shim, J.S., Lee, J.S., Lee, J.Y., Choi, Y.J., Shin, S.W. and Ryu, J.J. Effect of software version and parameter settings on the marginal and internal adaptation of crowns fabricated with the cad/cam system. *J. Appl. Oral Sci.*, 2015;**23**:515.522.
14. Alajaji, N.K., Bardwell, D., Finkelman, M. and Ali, A. Micro-ct evaluation of ceramic inlays: comparison of the marginal and internal fit of five and three axis CAM systems with heat press technique. *J. Esthet. Restor. Dent.* 2017;**29**:49.58.
15. Lu, L., Lıu, S., Shi, S. and Yang, J. An open CAM system for dentistry on the basis of China-made 5-axis simultaneous contouring CNC machine tool and industrial CAM software. J. Huazhong. Univ. *Sci. Technolog. Med. Sci.*, 2011;**31**:696.700
16. Neves, Fd., Prado, C.J., Prudente, M.S., Carneıro, T.A, Zancopé, K. and Davı, L.R. Microcomputed tomography evaluation of marginal fit of lithium disilicate crowns fabricated by using chairside CAD/CAM systems or the heat-pressing technique. *J. Prosthet. Dent.*, 2014;**112**:1134.1140.
17. Vennerstrom, M., Fakhary, M. and Von Steyern, P.V. The fit of crowns produced using digital impression systems. *Swed. Dent. J.*, 2014;**38**:101.110.
18. Renne, W., Ludlow, M., Fryml, J., Schurch, Z., Mennıto, A., Kessler, R. and Lauer, A. Evaluation of the accuracy of 7 digital scanners: An in vitro analysis based on 3-dimensional comparisons. *J. Prosthet. Dent.*, 2017;**118**:36.42.
19. Haddadi, Y., Bahrami, G. and Isidor, F. Effect of software version on the accuracy of an intraoral scanning device. *Int. J. Prosthodont.*, 2018;**31**:375.376.
20. Naert, I., Van der Donck, A. and Becjers, L. Precision of fit and clinical evaluation of all-ceramic full restorations full restorations followed between 0.5 and 5 years. *J. Oral. Rehabil.*, 2005;**32**:51.57.
21. Son, K., Lee, W. and Lee, K. Prediction of the learning curves of 2 dental CAD software programs. *J. Prosthet. Dent.*, 2019;**121**:95.100.
22. Seo, D., Yi, Y. and Roh, B. The effect of preparation designs on the marginal and internal gaps in CEREC3 partial ceramic crowns. *J. Dent.* 2009;**37**:374.382.